DE LA RECHERCHE À L'INDUSTRIE

Pu239
Resolved Resonance Range

Contribution CEA Cadarache

CSWEG/CIELO, 3-5 November 2014, BNL, USA

Outlines

- Thermal quantity and resonance integral
- Performance of JEFF-311 and JEFF-32 on PST and MOX fuel calculations
- PFNS issues for CIELO
- Thermal fission cross section and nubar
- Target uncertainty for the capture cross section
- Extension of the Resolved Resonance Range up to 4.5 keV

Thermal quantity and resonance intégral

Quantity	Atlas	JEFF-32 (=SG34)	P. Romano C. Lubitz	D. Rochman « run 6174 »
Thermal fission cross section	748.1±2.0 (0.3%)	747.2±6.7 (0.9%)	747.2	771.7
Thermal capture cross section	269.3±2.9 (1.1%)	270.1±11.9 (4.4%)	270.1	271.0
Fission resonance integral	303±10 (3.3%)	308.8±7.1 (2.3%)	308.3	309.1
Capture resonance integral	180±20 (11.1%)	180.1±10.3 (5.7%)	180.0	182.2
Thermal fission nubar	2.879±0.006 (0.2%)	2.875	2.875	2.871
Equivalent K1	1177.0	1161.5±19.7 (1.7%)	1161.4	1209.0

NB: performances of « run 6174 » were discussed during the PND-2 workshop: ftp://ftp.nrg.eu/pub/www/talys/bib_rochman/tendl.bruyeres.oct.2014.pdf

Performance of JEFF-311 and JEFF-32 : PST/MOX calculations

Quantity	Atlas	JEFF-32 (=SG34)	P. Romano C. Lubitz	D. Rochman « run 6174 »
Thermal fission cross section	748.1±2.0 (0.3%)	**747.2±6.7** (0.9%)	747.2	771.7
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Excellent performance of JEFF-32 for MOX fuel calculations $\Rightarrow$ PST, EOLE, MINERVE

Performance of JEFF-311 : PST calculations

S. C. van der Marck
Nucl. Data Sheets 113 (2012) 2935

(average value over 368 PST)

TABLE XIX: The average values for $C/E-1$ (in pcm) for ENDF/B-VII.1 per main ICSBEP benchmark category.

	COMP				MET				SOL	MIXED	
	therm	inter	fast	mixed	therm	inter	fast	mixed	therm	therm	fast
LEU	−80				553				133		
IEU	101	−253	−70				103		396		
HEU	746	2112		−892	130	−65	114	844	16		
MIX	402		16				418		−194	322	−845
PU		1119		1960		2950	164	921	462		
U233	23						−220		549		

WPEC/SG34 ⇒ the **non-regression** of the Pu239 nuclear data was continuously monitored during the evaluation procedure with a selected set of ICSBEP benchmakrs

TABLE XX: The average values for $C/E-1$ (in pcm) for JENDL-4.0 per main ICSBEP benchmark category.

	COMP				MET				SOL	MIXED	
	therm	inter	fast	mixed	therm	inter	fast	mixed	therm	therm	fast
LEU	−29				736				−90		
IEU	87	−257	−209				−435		487		
HEU	985	2982		−497	397	209	31	948	197		
MIX	501		446				194		16	588	−591
PU		1376		2030		3529	0	970	633		
U233	25						−195		177		

Crucial step to conserve the good performances of the JEFF library on PST benchmarks

TABLE XXI: The average values for $C/E-1$ (in pcm) for JEFF-3.1.1 per main ICSBEP benchmark category.

	COMP				MET				SOL	MIXED	
	therm	inter	fast	mixed	therm	inter	fast	mixed	therm	therm	fast
LEU	−52				527				179		
IEU	−107	−468	258				−180		425		
HEU	381	1912		−1221	−45	145	−106	628	−56		
MIX	258		300				251		−274	87	−867
PU		692		1852		3275	95	478	203		
U233	−312						363		247		

Performance of JEFF-32 : PST calculations

S. C. van der Marck
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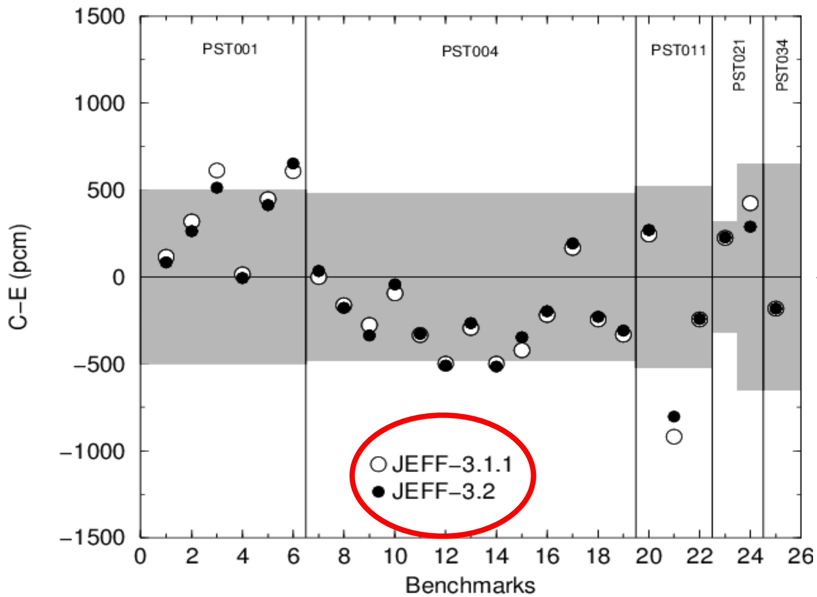


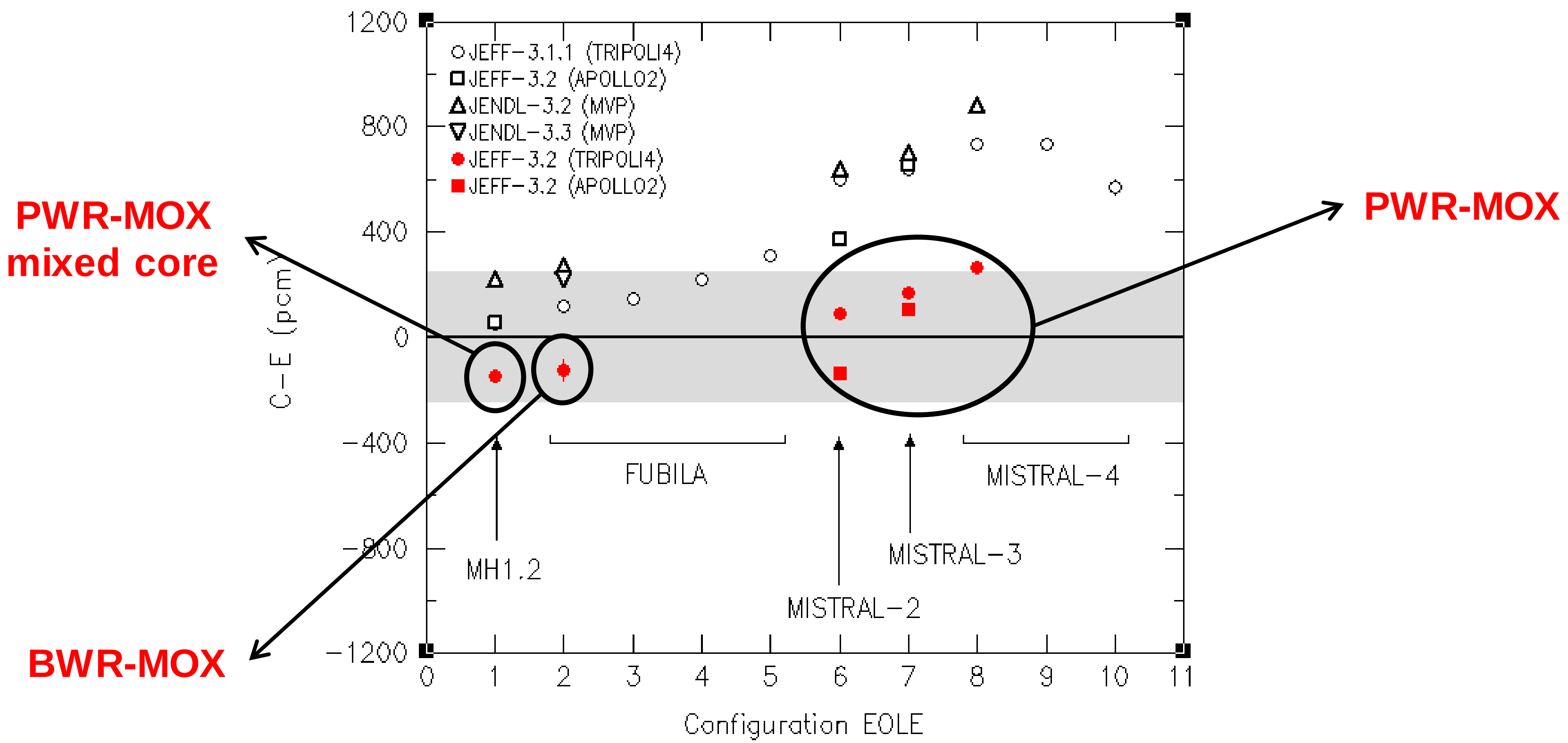
Y. Peneliau , JEFFDOC-1583, 2014
O. Caballos, JEFFDOC-1532, 2014

JEFF-311 and JEFF-32 $\Rightarrow$ **Similar results for Plutonium in THERM spectrum**

Performance of JEFF-32 : MOX calculations

Integral experiments carried out in the EOLE reactor of CEA Cadarache

Interpretation with the Monte-Carlo and deterministic codes TRIPOLI and APOLLO



Several experimental programs were conducted by CEA to investigate the use of MOX fuel in commercial PWRs or innovative concepts for various moderation ratios

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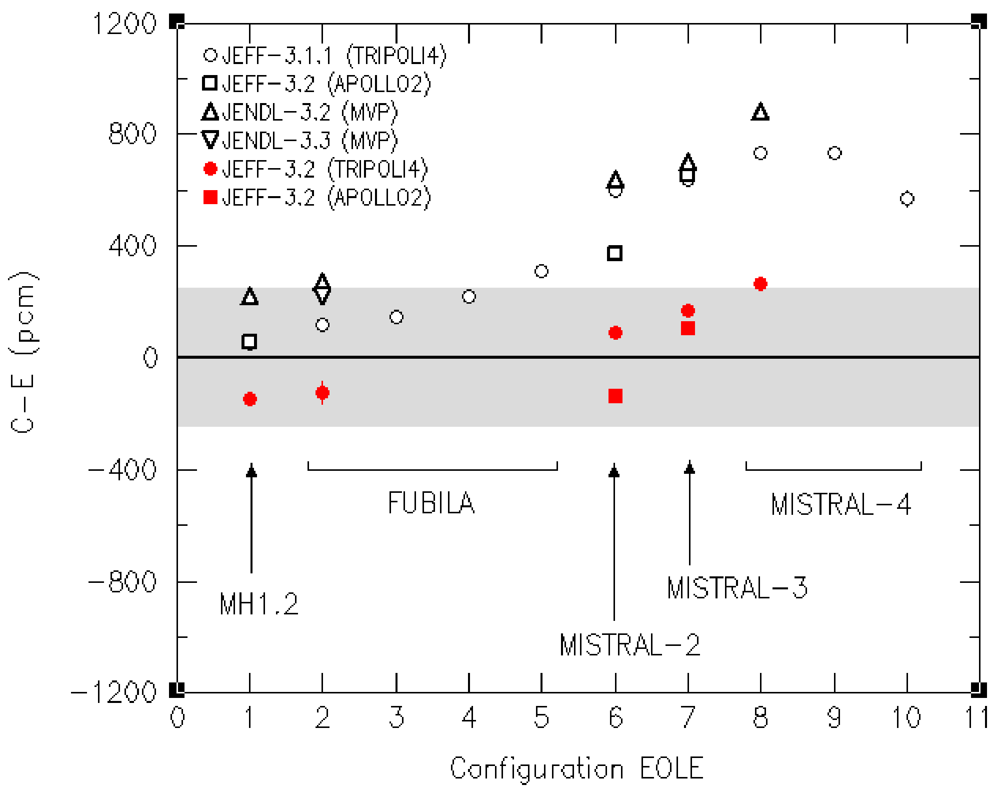

Average value obtained with JEFF-32 $\Rightarrow$ **⟨C-E⟩=+50 pcm** with a standard deviation of **180 pcm**

PFNS issues for CIELO

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Strategy for CIELO ? ⇒ use SG34 with adjusted Prompt Fission Neutron Spectrum

PFNS issues for CIELO

Impact of the mean neutron energy uncertainty on PST calculations

Y. Peneliau et al., Pu239 Prompt Fission Neutron Spectra Impact on a Set of Criticality and Experimental Reactor Benchmarks, ND2013 (2013)

Authors	years	⟨E⟩	Δ[⟨E(PFNS)⟩,⟨E(JEFF-32)⟩]	Δ[keff(PFNS),keff(JEFF-32)]
N. Kornilov	2008	2,055	-2,8%	+680 pcm
L. Berge	2014	2,087	-1,2%	+316 pcm
V. Maslov	2008	2,092	-1,0%	+250 pcm
JEFF-32	**2013**	**2,113**	**0%**	**0 pcm**
P. Romano	2014	2,122	+0,4%	-90 pcm
O. Serot	2013	2,140	+1,3%	-290 pcm
D. Rochman	2014	2,195	+3,9%	-890 pcm

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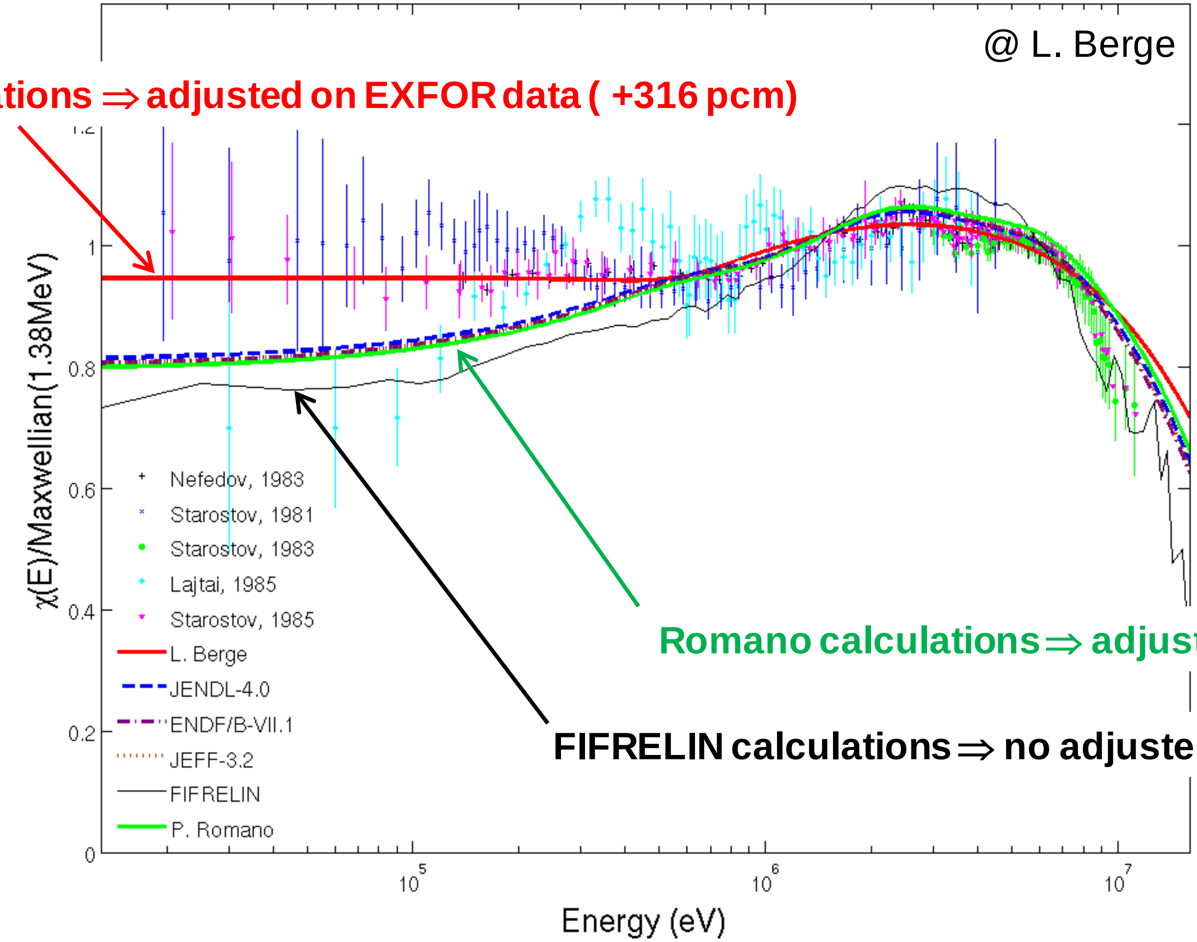
Uncertainty suggested by R. capote ⇒ **Δ⟨E⟩ = ± 1.5% ⇒ Δkeff(PST) ≈ ± 300 pcm**

PFNS issues for CIELO

Impact of the mean neutron energy uncertainty on PST calculations



CONRAD calculations ⇒ adjusted on EXFOR data (+316 pcm)

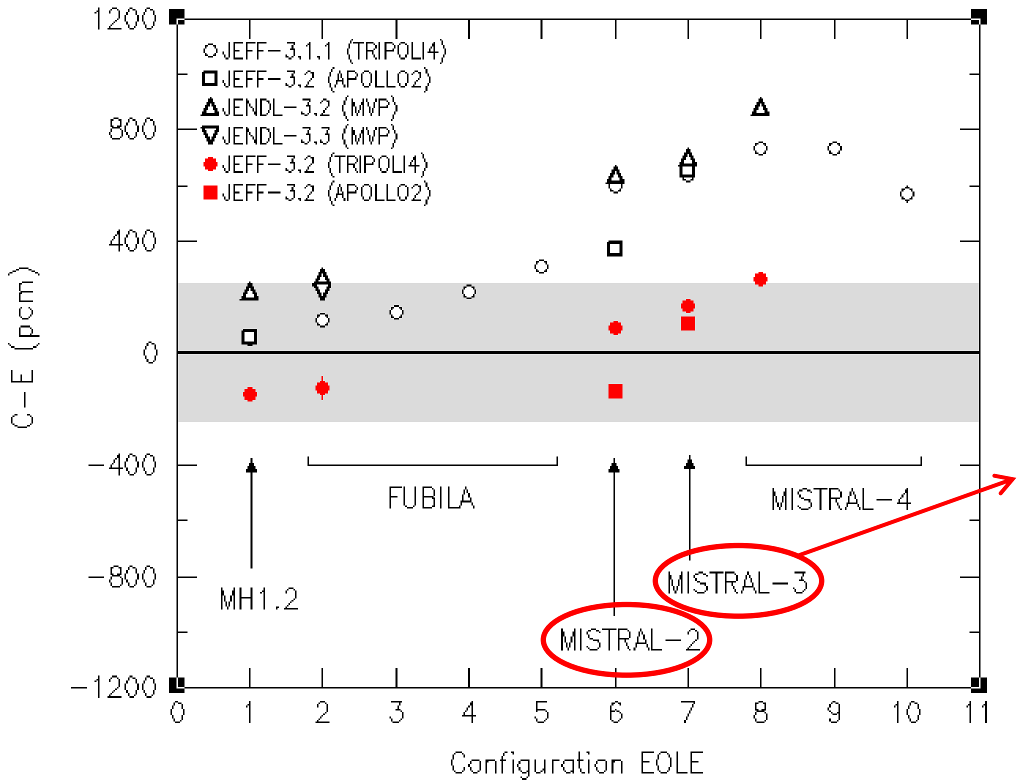
Romano calculations ⇒ adjusted on PST (-90 pcm)

FIFRELIN calculations ⇒ no adjustement (-290 pcm)

Adjustement of the mean neutron energy with PST **⇒ not recomended !**

PFNS issues for CIELO

Impact of the mean neutron energy uncertainty on MOX fuel calculations



$\Delta\langle E\rangle = \pm 1\% \Rightarrow$ **± 50 pcm**

mean neutron energy uncertainty $\Rightarrow$ **negligible impact on EOLE benchmarks**

Thermal fission cross section and nubar

Quantity	Atlas	JEFF-32 (=SG34)	P. Romano C. Lubitz	D. Rochman « run 6174 »
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Equivalent K1	1177.0	1161.5±19.7 (1.7%)	1161.4	1209.0

+3.3%

+4.1%

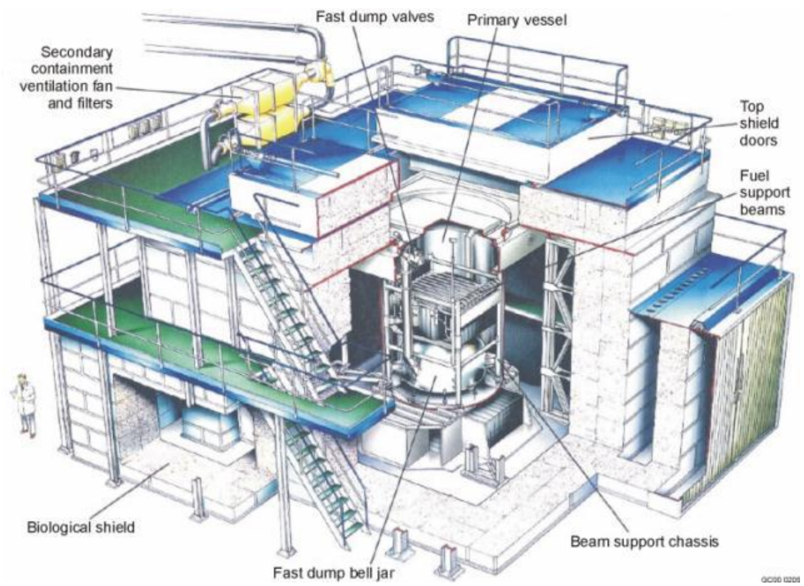
TENDL corrections seem to be too high ⇒ Cf. interpretation CERES-PU experiment

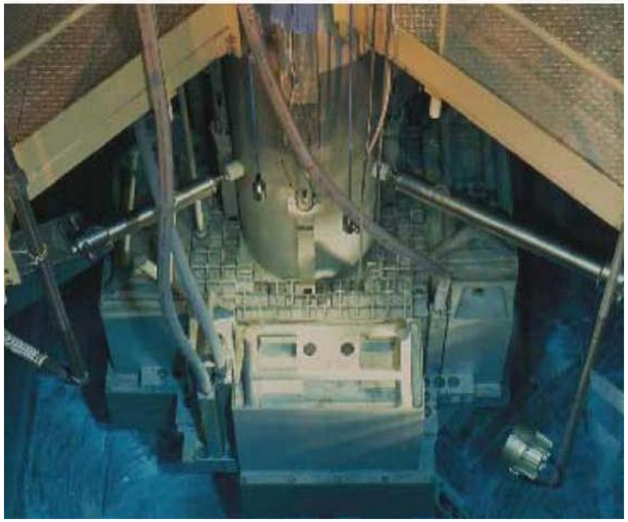
the complete file should be "discussed"

Thermal fission cross section and nubar

CERES program (P. Leconte, PHYSOR 2014)

- Collaboration between Winfrith and Cadarache (1992-1995) as part of the CEA/UKAEA collaboration on LWRs
- Experiments conducted in the DIMPLE (AEA) and MINERVE (CEA) reactors on common samples, manufactured both at Cadarache and Winfrith
- Reactivity-worth measurements of fresh MOX fuel samples provided by CEA and AEA





Thermal fission cross section and nubar

Integral results for $\nu\Sigma_f$ (SG-34)

@ P. Leconte

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	-9.0
	$\nu\Sigma_f$	**98.5**
^{240}Pu	Σ_a	-0.9
^{241}Pu	Σ_a	-1.0
	$\nu\Sigma_f$	12.3

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	-17.8
	$\nu\Sigma_f$	**118.0**
^{240}Pu	Σ_a	-0.3
^{241}Pu	Σ_a	
	$\nu\Sigma_f$	0.1

Sample (Reference)	Full Monte Carlo Method C/E-1 (%)			
	Assembly-I	Assembly-II	Assembly-III	R1UO2
MOX1 (CEAU11)	**3.0 ± 4.9**	3.6 ± 9.3	10.9 ± 6.6	197 ± 9274
MOX2 (CEAU11)	**0.7 ± 3.2**	34.2 ± 22.8	5.7 ± 4.0	-59.2 ± 6.1
MOX3 (CEAU11)	**0.8 ± 1.7**	18.2 ± 4.8	2.9 ± 1.8	-79.6 ± 7.4
MOX4 (CEAU11)	**-0.7 ± 1.5**	9.6 ± 2.9	0.1 ± 1.3	-98 ± 8.7
MOX5 (CEAU11)	**-1.1 ± 1.3**	5.1 ± 1.5	-1.3 ± 1.1	97 ± 13.2
MOX6 (CEAU11)	**-1.5 ± 1.2**	1.4 ± 1.2		42 ± 7.8
Pu0403 (UO2nat)	**-2.4 ± 1.5**	-1.1 ± 4.0	-2.9 ± 2.4	-7.1 ± 4.5
Pu0413 (UO2nat)	**-2.9 ± 1.7**	-7.6 ± 6.8	-5.6 ± 2.6	-21.3 ± 10.2
Pu0426 (UO2nat)	**-6.6 ± 1.6**	-23 ± 5044	-8.1 ± 3.1	-93 ± 154
Pu2003 (UO2nat)	**1.1 ± 1.4**	0.1 ± 1.5	-0.7 ± 1.3	-7.7 ± 2.5
Pu2013 (UO2nat)	**0.4 ± 1.4**	3.0 ± 2.0	-0.8 ± 1.3	1.7 ± 3.9
Pu2026 (UO2nat)	**1.1 ± 1.4**	22.4 ± 5.1	2.1 ± 1.5	-140 ± 22

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	-17.9
	$\nu\Sigma_f$	**118.7**
^{240}Pu	Σ_a	-2.1
^{241}Pu	Σ_a	-0.3
	$\nu\Sigma_f$	2.0

Mean value = -1.0 ± 0.5 %
(standard deviation : 2.5%)

SG34 seems to be Ok !

Thermal fission cross section and nubar

Integral results for K1 (SG-34)

@ P. Leconte

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	**-88.2**
	$\nu\Sigma_f$	**185.5**
^{240}Pu	Σ_a	-7.9
^{241}Pu	Σ_a	-10.3
	$\nu\Sigma_f$	23.5

Sample (Reference)	Full Monte Carlo Method C/E-1 (%)			
	Assembly-I	Assembly-II	Assembly-III	R1UO2
MOX1 (CEAU11)	3.0 ± 4.9	3.6 ± 9.3	**10.9 ± 6.6**	197 ± 9274
MOX2 (CEAU11)	0.7 ± 3.2	34.2 ± 22.8	**5.7 ± 4.0**	-59.2 ± 6.1
MOX3 (CEAU11)	0.8 ± 1.7	18.2 ± 4.8	**2.9 ± 1.8**	-79.6 ± 7.4
MOX4 (CEAU11)	-0.7 ± 1.5	9.6 ± 2.9	**0.1 ± 1.3**	-98 ± 8.7
MOX5 (CEAU11)	-1.1 ± 1.3	5.1 ± 1.5	**-1.3 ± 1.1**	97 ± 13.2
MOX6 (CEAU11)	-1.5 ± 1.2	1.4 ± 1.2		42 ± 7.8
Pu0403 (UO2nat)	-2.4 ± 1.5	-1.1 ± 4.0	**-2.9 ± 2.4**	-7.1 ± 4.5
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Pu2003 (UO2nat)	1.1 ± 1.4	0.1 ± 1.5	**-0.7 ± 1.3**	-7.7 ± 2.5
Pu2013 (UO2nat)	0.4 ± 1.4	3.0 ± 2.0	**-0.8 ± 1.3**	1.7 ± 3.9
Pu2026 (UO2nat)	1.1 ± 1.4	22.4 ± 5.1	**2.1 ± 1.5**	-140 ± 22

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	**-100.8**
	$\nu\Sigma_f$	**202.4**
^{240}Pu	Σ_a	-1.6
^{241}Pu	Σ_a	
	$\nu\Sigma_f$	0.1

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	**-113.6**
	$\nu\Sigma_f$	**228.2**
^{240}Pu	Σ_a	-13.9
^{241}Pu	Σ_a	-1.8
	$\nu\Sigma_f$	3.8

SG34 seems to be Ok !

Mean value = -0.4 ± 0.5 %
(standard deviation : 5.2%)

Target uncertainty for the capture cross section

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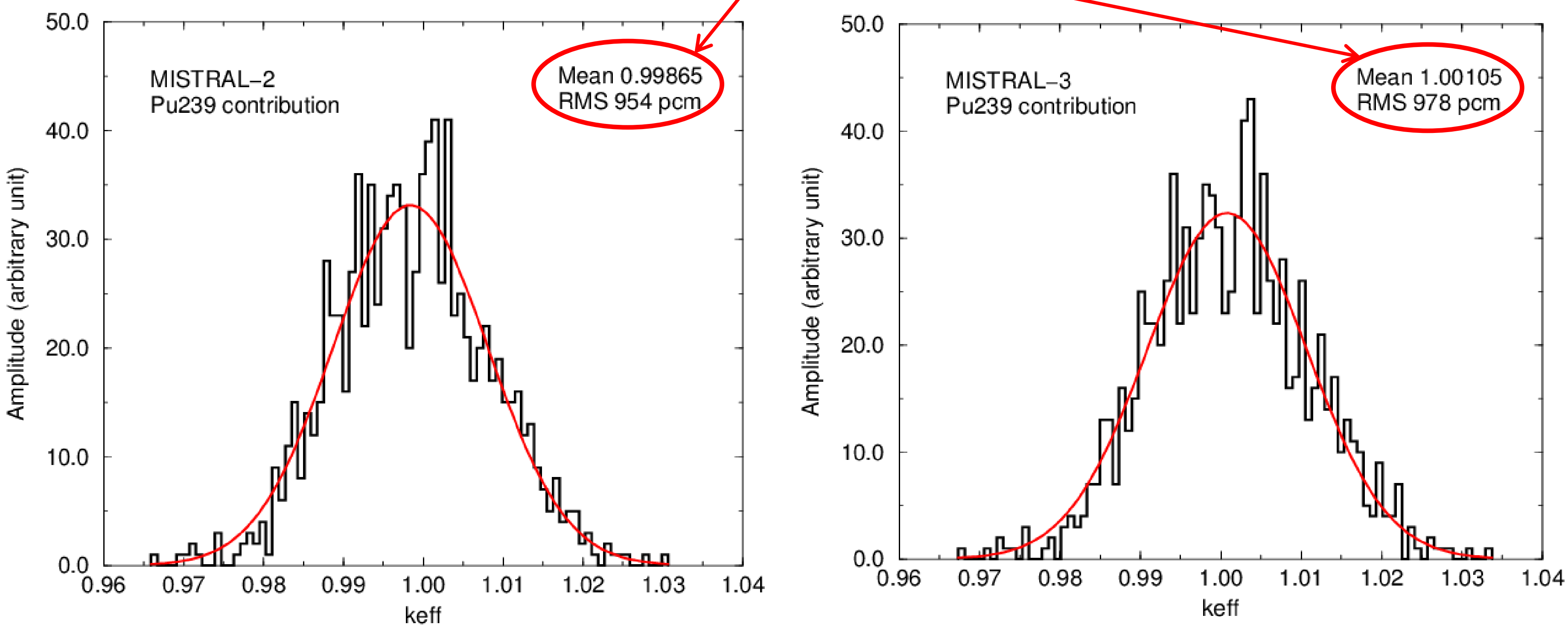
Reduction of the uncertainties $\Rightarrow$ Integral Data Assimilation procedure of CONRAD

Target uncertainty for the capture cross section

Propagation of the Pu239 resonance parameter uncertainties on EOLE benchmarks

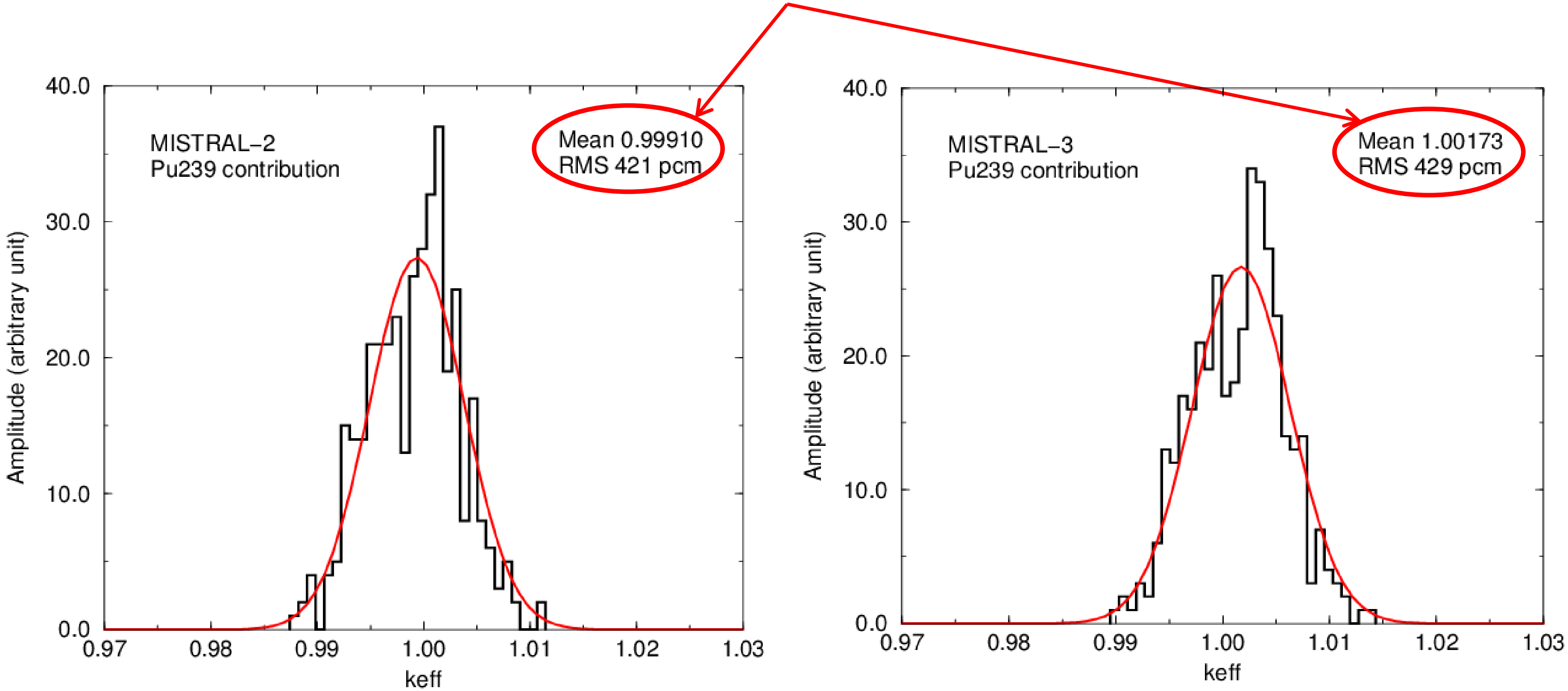
Final uncertainty (**≈1000 pcm**) ⇒ dominated by the capture cross section uncertainties



Target uncertainty for the capture cross section

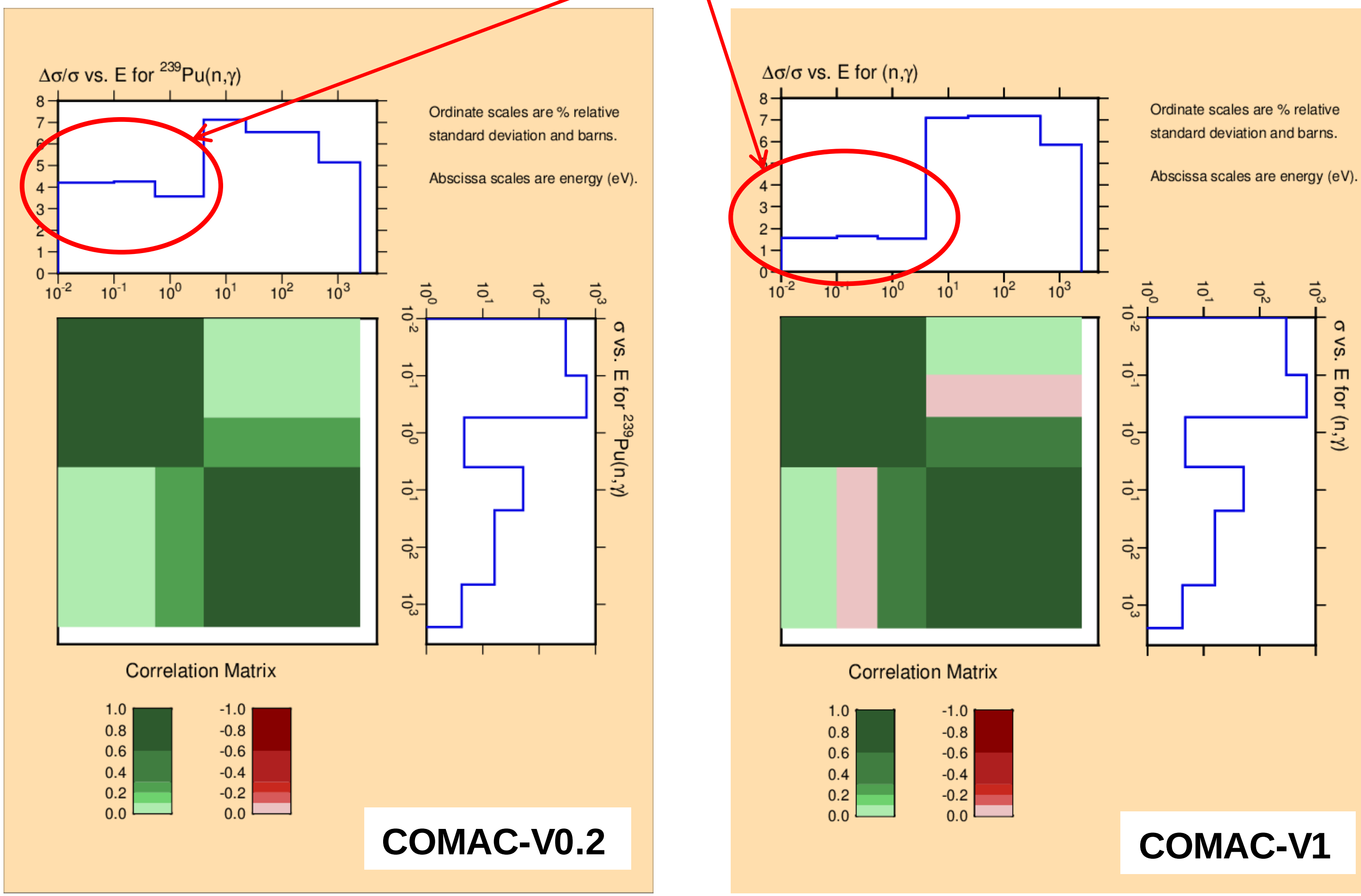
Propagation of the Pu239 resonance parameter uncertainties on EOLE benchmarks

Final uncertainty (**≈400 pcm**) after the Integral Data Assimilation of CERES (P. Leconte)



Target uncertainty for the capture cross section

Significant reduction of the Pu239 capture cross section uncertainties at low neutron energy



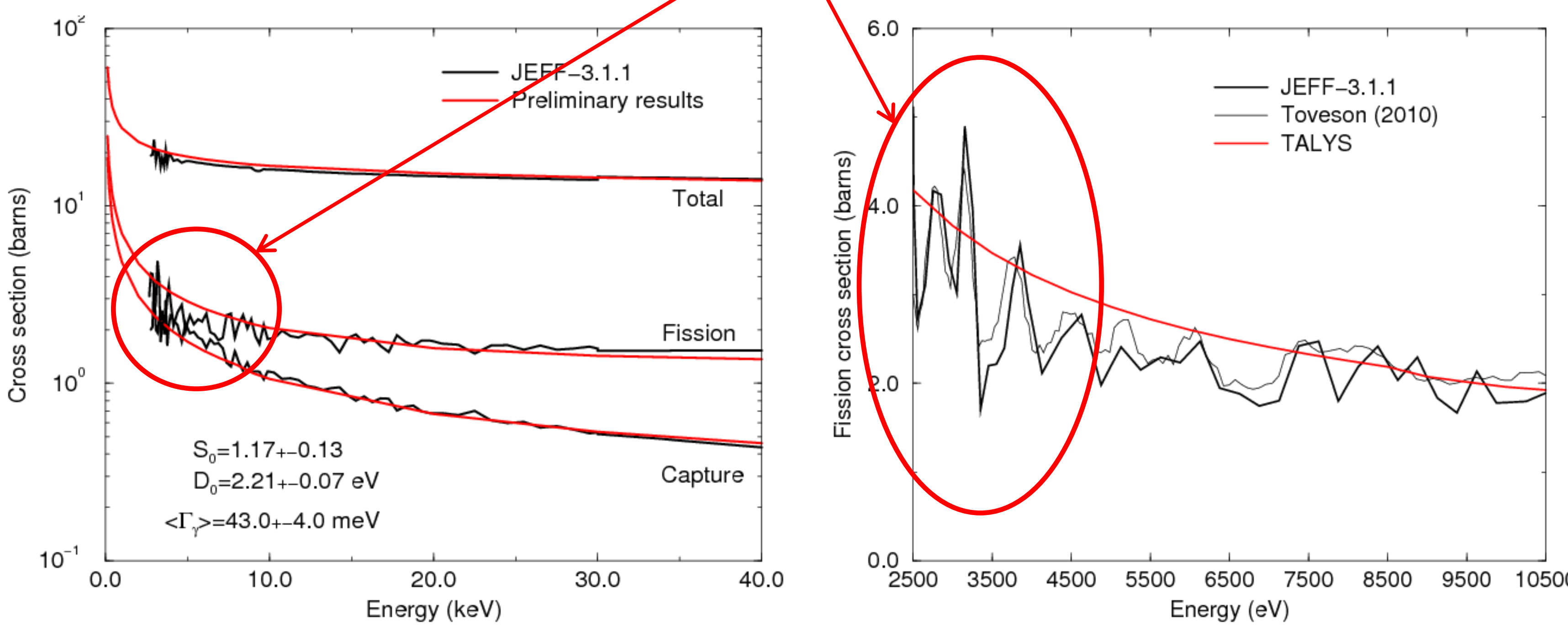
Target uncertainty for the capture cross section

Final uncertainties after the Integral Data Assimilation of the CERES program

	JEFF-3.2 (=SG34)	Relative uncertainty	
		JEFF-3.2	This work
σ_f	747.2 barns	0.9%	0.7%
σ_γ	**270.1 barns**	**4.4%**	**1.6%**
I_f	308.8 barns	2.3%	2.3%
I_γ	180.1 barns	5.7%	5.7%
K1	1161.5 barns	1.7%	0.9%

Extension of the RRR up to 4.5 keV

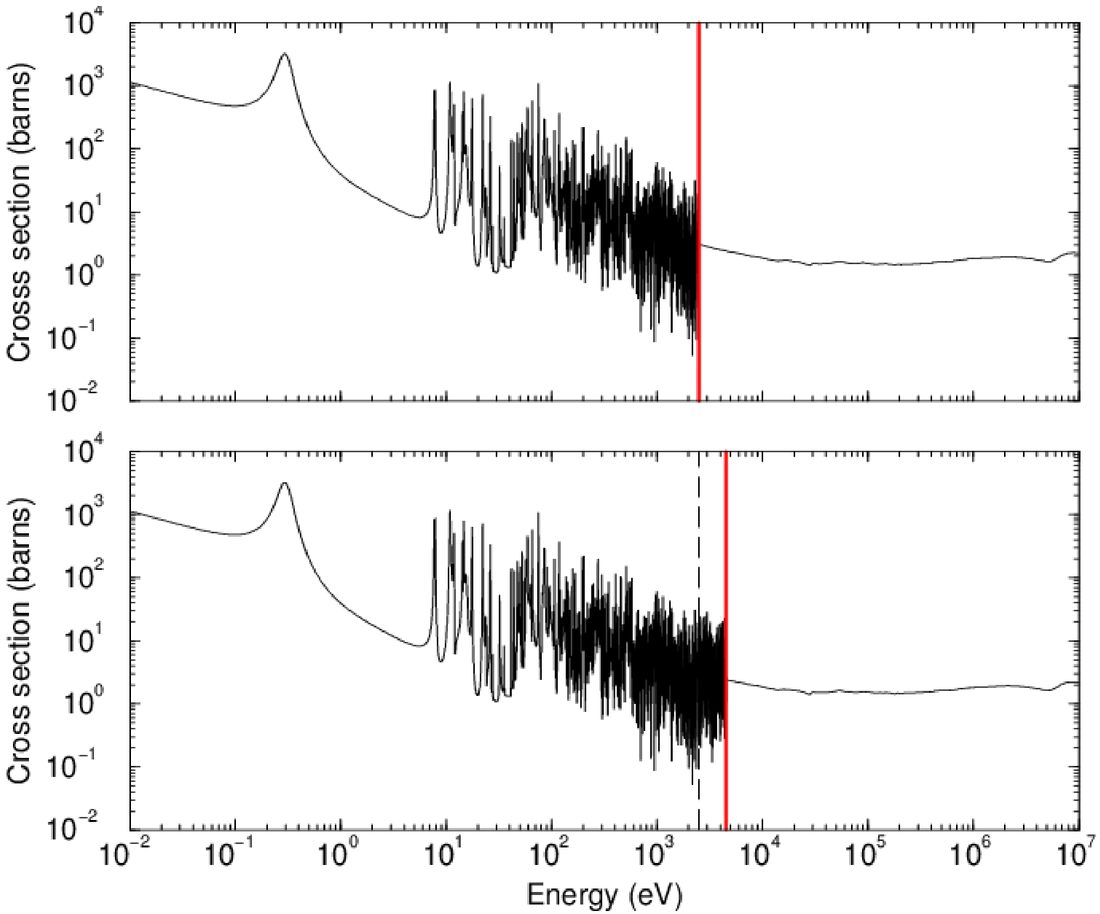
Fluctuations between 2.5 keV - 4.5 keV not taken into account via statistical calculations



Fluctuations observed in JEFF-311 ⇒ **confirmed by Tovesson data (2010, LANL)**

Extension of the RRR up to 4.5 keV

Random generation of resonance ladders by using URR parameters from JEFF-311



Extension of the RRR up to 4.5 keV

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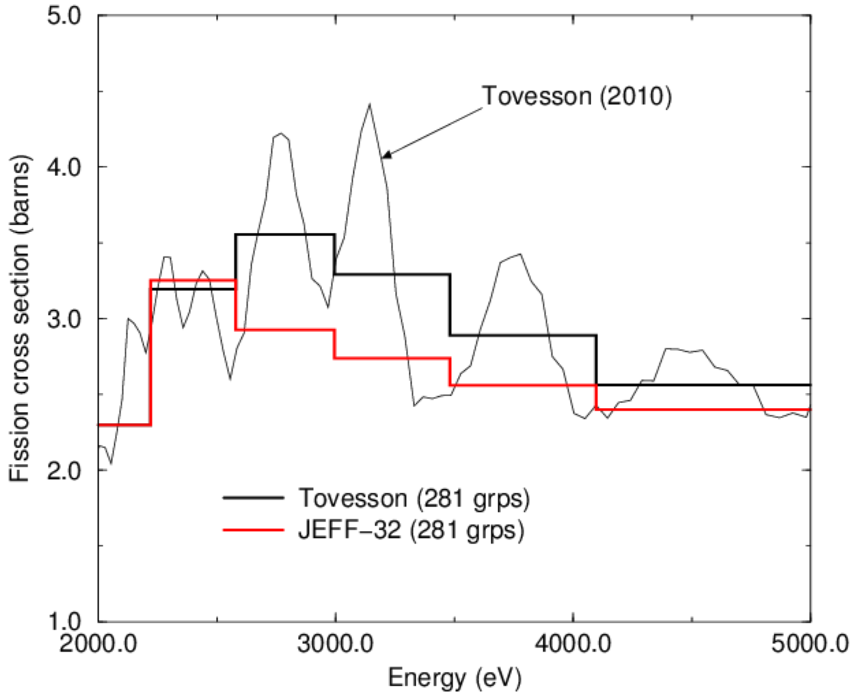
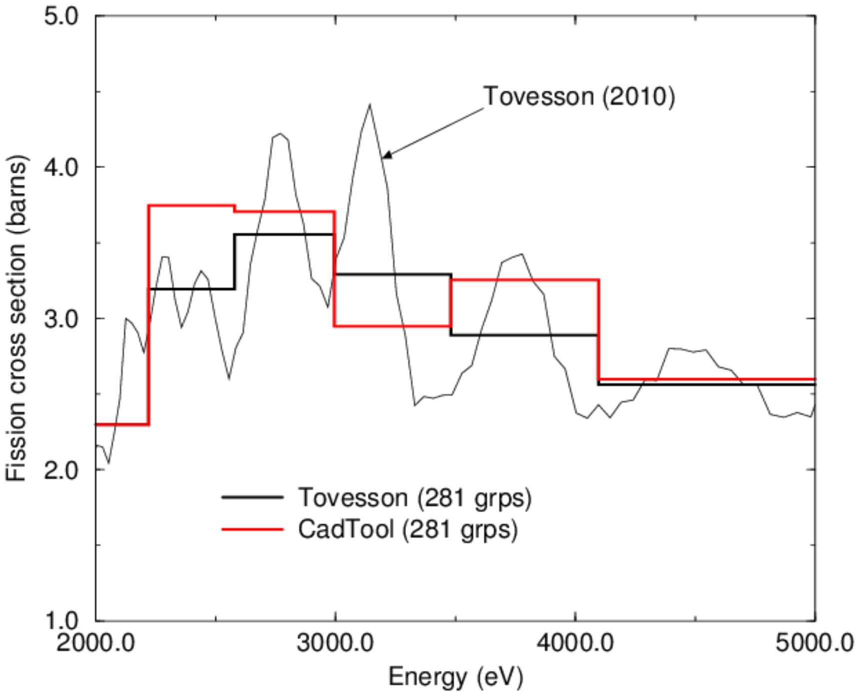


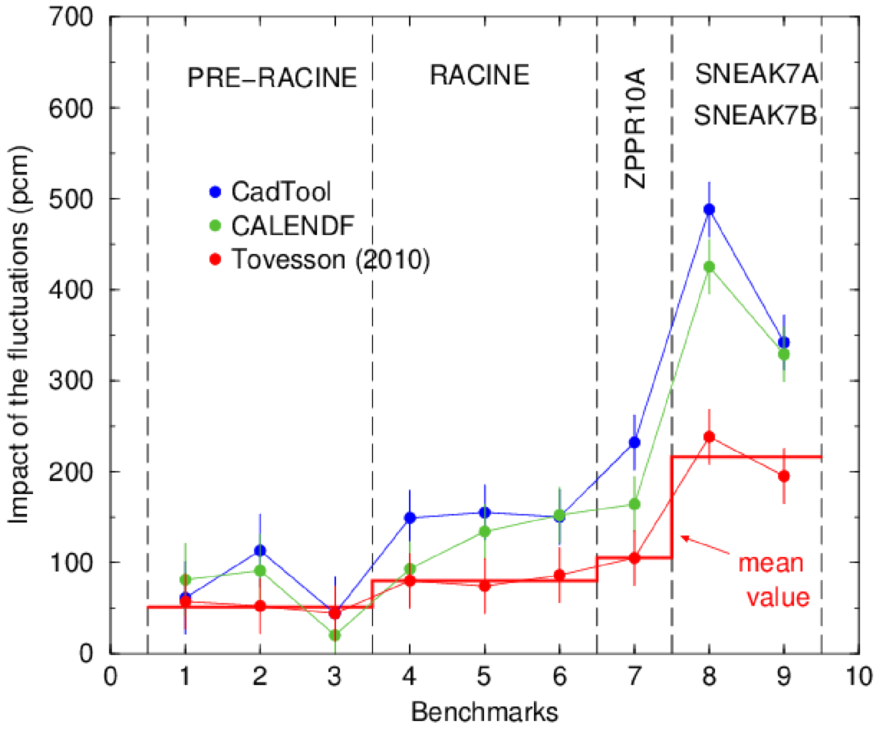


JEFF-32 underestimates the data

Préliminary set of resonance ladders

Extension of the RRR up to 4.5 keV

Impact of the fluctuations in integral benchmarks



Our preliminary sets of resonance ladders (generated by CALENDF and CadTool) overestimate the impact of the fluctuations

Adjustement of the URR parameters in progress with the CONRAD/TALYS codes

Significant impact (≈ 200 pcm) on SNEAK7A and SNEAK7B ⇒ **sodium free configurations**

Conclusions

☑ **Integral Data Assimilation of CERES**

$\Rightarrow$ reduction of the capture cross section uncertainty (± 1.6%)

☑ **Contribution of the neutron cross sections (COMAC-V1)**

$\Rightarrow$ $\Delta\rho \approx \pm 400$pcm (for thermal systems)

☑ **Contribution of PFNS**

$\Rightarrow$ $\Delta\rho \approx \pm$ 300pcm (for PST), $\Delta\rho \approx \pm$ 50pcm (for EOLE)

☐ **Contributions of URR fluctuations (in progress)**

$\Rightarrow$ $\Delta\rho <$ 100 pcm (with Na), $\Delta\rho \approx \pm 200$ pcm (without Na)

☐ **Contributions of the (n,γf) reaction**

$\Rightarrow$ to be investigated ...